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16. ABSTRACT

The monitoring of ambient air quality is of paramount importance for determining ambient levels of pollutants so that they can be related to adverse effects on man and his environment. The considerations and objectives for designing and implementing an air quality monitoring network are reviewed.

The types of air monitoring activities are discussed covering permanent fixed site (trend) monitoring, ambient source-linked monitoring, exposure monitoring, and biological monitoring. The components of an ambient air quality monitoring network are reviewed and evaluated along with the quality control program necessary to assure that the data and supporting information are legally and scientifically defensible.

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Monitoring the quality of ambient air

To set standards, assure compliance, develop controls and anticipate problems

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Monitoring of ambient air quality permits the quantification of pollutants and the documentation of their effects on man and his environment. This monitoring also quantitatively relates air quality and pollutant sources so that the efficacy of control measures, and thus compliance with standards, can be determined.

Air pollution measurements have been made for nearly 100 years. Most early air pollution efforts focused on smoke control. Before the middle 1950's, 18 U.S. cities made sporadic measurements of one or more gaseous pollutants, namely, hydrogen sulfide, oxides of nitrogen, ammonia, carbon monoxide, fluorides, oxidants, hydrocarbons, and aldehydes. In 1954, Los Angeles County established a 12-station continuous air-monitoring network that measured particulate matter, carbon monoxide (CO), nitrogen oxide (NO), total oxides of nitrogen (NO_x), total oxidants, sulfur dioxide (SO_2), and hydrocarbons. Other cities soon implemented air-monitoring networks when federal financial assistance for state programs became available in 1963.

The Air Quality Act of 1967 underlies much of the current air pollution control effort: the development of air quality standards and the enforcement of these standards on a regional basis. The Clean Air Act Amendments of 1970 and subsequent amendments form the basis for current air pollution control activities and for necessary air pollutant measurement systems.

However, many of the monitoring efforts have resulted in less than adequate data, have not been cost effective and, in certain instances, have resulted in costly programs that provided questionable benefits. As they become available, new concepts and methodologies must be maximally utilized. Such concepts as integrated monitoring systems, new optimization techniques, and state-of-the-art measurement devices, such as remote-sensing techniques, are becoming available for testing and application; failure to use them to their fullest capabilities will result in a loss of the opportunity to develop rational environmental assessment tools.

The ability to assess ambient air quality depends heavily on the availability and applicability of appropriate sensors. Until recently, most pollutant sensors capable of providing quantitative information were of the in-situ or contact type. Such sensors are restricted to measurement of a parameter at a single point or, when mounted on a mobile platform, at sequential points as a function of time. As a result of the difficulty in relating a point remote from the sensor to the collected data, great care must be taken in selecting the sensor placement site. Even the use of a dense array of sensors (a prohibitively expensive undertaking) provides information only between sensors, and then by interpolative techniques. This problem may be skirted by the appropriate application of remote sensors, which are generally capable of extensive, rapid measurement of a profile or array of points.

Reasons for monitoring

Monitoring for air quality is a very complex operation, one which requires a pollutant specific systematic approach. Without an approach based on stated objectives and guidelines, proper ambient air quality assessment cannot be accomplished. Failure to recognize the complexities associated with ambient air quality has led to the present situation: the inability to document the relationship between sources and exposure, or between exposure and effects.

Nevertheless, once an air-monitoring network has been properly designed, it can furnish data to be used:

- to establish or revise standards
- to demonstrate that adequate progress is being made toward attainment of the standards
- to demonstrate that compliance with standards is maintained
- to furnish information during high-pollution episodes or accidental discharges and provide guidance on choice of subsequent actions
- to define air pollution problems for periodic determination

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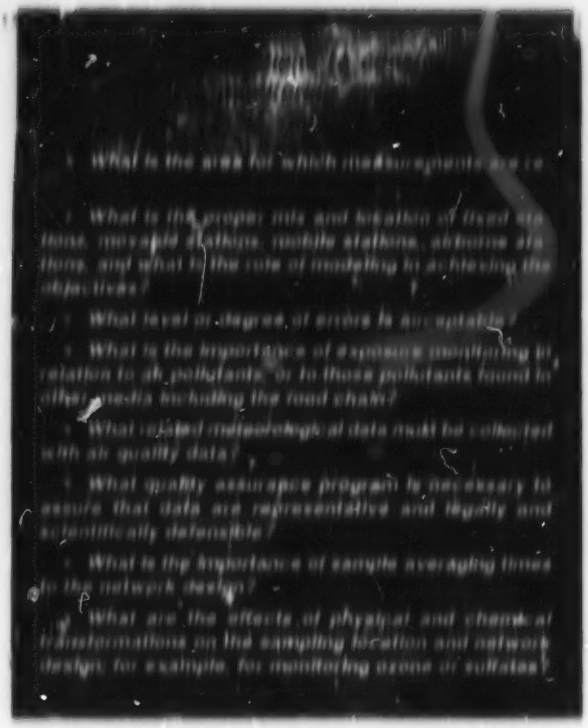
Airborne platforms. *This type of monitoring is efficient and cost effective for urban areas and long-range transport studies*

Simulation model. *The model can be used to site air-monitoring stations within an airshed through the development of pollution distribution maps*

Monitoring helicopter. *Well-equipped to monitor the six criteria pollutants, this helicopter is measuring sulfur dioxide in the plume from a copper smelter*


What is the area for which measurements are re
What is the proper mix and location of fixed sta tions, mobile stations, airborne sta tions, and what is the role of modeling in achieving the objectives?
What level or degree of error is acceptable?
What is the importance of exposure monitoring in relation to air pollutants or to those pollutants found in other media including the food chain?
What related meteorological data must be collected with air quality data?
What quality assurance program is necessary to ensure that data are representative and legally and scientifically defensible?
What is the importance of sample averaging times in the network design?
What are the effects of physical and chemical transformations on the sampling location and network design for example, for monitoring ozone or sulfates?

of priorities for resource allocations, and to develop control programs.

Today's national air-monitoring program is an integrated effort involving local, regional, state and federal agencies; but the majority of the actual data are being collected by state and local agencies. In many cases, state and local agencies, possessing detailed knowledge of local meteorology, topography, demography, pollutant sources, and emissions, have programs that exceed present EPA requirements.

The primary goal of state and local programs is to show compliance with national ambient air quality standards for particulate matter, SO_2, CO, nitrogen dioxide (NO_2), and photochemical oxidants. The primary goal of the federal monitoring program is to provide special air-monitoring data not furnished by state and local agencies, and to make available meteorological, aerometric and related data on a nationwide scale.

Present air monitoring must be expanded to provide an effective capability to detect and quantify ambient levels of toxic or nonregulated pollutants that may pose a threat to human health and welfare. In order to accomplish this, a priority list of toxic pollutants must be assembled. For those pollutants that are transported from one medium to another, an air-monitoring program must be developed in conjunction with other appropriate monitoring programs so that *total* exposure to important receptors may be quantified.

Establishing priorities for monitoring and controlling pollutants must be based on demonstrated effects, the probability that projected benefits will be commensurate with resources expended, and public concern. Some factors that should be considered in establishing pollutant priorities include: the severity of known or suspected effects on human health, soil, plants and other animals; the persistence and accumulation of the pollutant in man or his food chain; the availability of adequate measurement and control technology; and legal mandates.

Types of monitoring

Air monitoring activities may be divided into permanent-fixed-site (trend) monitoring, exposure monitoring, ambient-source-linked monitoring, and biological monitoring.

Permanent-fixed-site (trend) monitoring is necessary to judge the attainment and maintenance of the present ambient air quality standards through the State Implementation Plans (SIP's). Monitoring of trends at permanent sites involves the measurement of pollutants and their effects over extended periods of time.

In urban or industrial areas, trend data are used to evaluate local, regional, and national long-term trends in pollutant levels and their effects on the ecosystem. These data are also necessary to determine the effectiveness of pollution control efforts as well as to alert epidemiologists to possible causes of adverse health effects.

Trend monitoring furnishes information of the impact of urbanized areas on remote or non-urban areas and is frequently referred to as baseline data. Subtle low-level changes in the baseline concentrations of pollutants yield the first indication of pollutants' effects on weather and climate modifications. These changes also identify pollutant pathways across the various media, identify regional and global transport, and identify the persistence and ubiquity of pollutants in the biosphere. Trend monitoring also involves the quantitative and qualitative evaluation, on a long-term basis, of emissions of pollutants from various sources.

Ambient-source-linked monitoring relates air quality to sources through modeling. But taken into consideration are other pertinent supporting data such as meteorology, demography, and topography. Several techniques, ranging from simple to complex, can be used.

A gross estimate of emission inventories can be derived from published data. For most urban and industrial areas, published statistics are available on quantities and types of fuels consumed, number and types of vehicles registered, population, types and number of industries, and typical emissions from each type. The most useful and complete type of source-emissions inventory involves actual measurements to obtain area and temporal variations.

Computer models are being used extensively to provide a mathematical relationship between emission sources and air quality. These models are normally validated on the basis of air quality measurements for a limited number of points and time periods, which are then used to extrapolate or predict the variations of pollutant concentrations at points and times that are not measured directly. Once models are validated they provide a basic tool for assessing the effectiveness of abatement strategies for immediate or long-term problems.

Models developed to date have been used with some degree of success, particularly when used to extend and interpret information on stable pollutants. Modeling can never completely replace direct measurements, but it can drastically reduce the number of monitoring sites necessary and thus significantly reduce costs.

Models have been developed for pollutants that undergo physical and chemical transformations, but these models presently lack proper field evaluation and validation. It is, therefore, necessary to carefully delineate the situations and problems for which valid models are available.

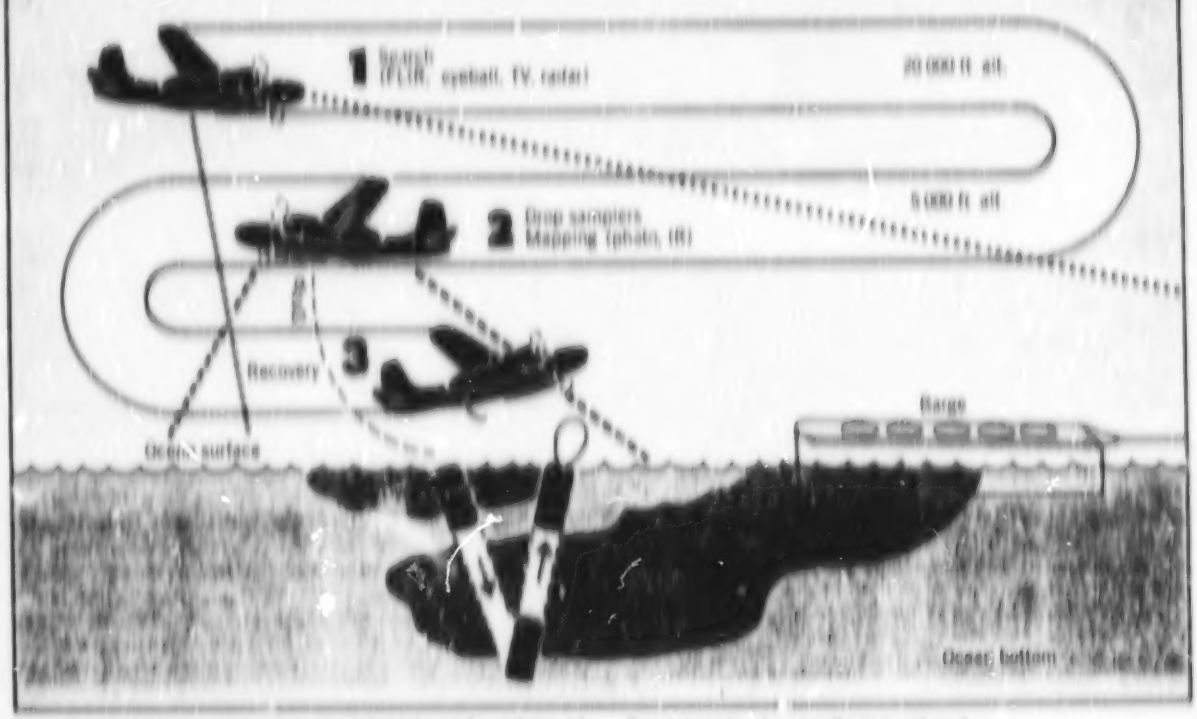
Much of research monitoring falls into the ambient-source-linked category. Projects that typically require significant monitoring support include studies of the movement, distribution, fate, pathways and effects of a specific pollutant entering a given environmental medium, and assessment of the effectiveness of experimental control systems or procedures.

Exposure monitoring should give a true picture of the impact of air pollution control on reduction of exposures and the resulting adverse effects on human health and welfare. An exposure-monitoring system is the preferred way of reporting progress toward cleaning the air and thus complying with the intent of the Clean Air Act.

Monitoring exposure systems measure pollutant concentration at locations where exposure may occur. The primary requirements for such systems are:

- The identification of critical receptors at risk and the pollutants that produce the adverse effects.

Air dropable/recoverable water samplers for ocean dumping monitoring



- The development of siting requirements and numbers of sites, including mobile and remote measurement systems, based on the time and variability of pollutant concentrations and the relevant receptor population.
- The integration of networks for estimating receptor exposure with networks for other purposes, such as standards attainment and maintenance.

Acute or chronic health effects may result from short-term peak exposure; repeated short-term high exposures; or a low-level, long-term exposure. The relationships between elevated short-term exposures or acute exposures and health effects are more easily recognized than are those for low-level exposure. Effects from chronic low-level exposures can be in the form of new disorders or aggravation of existing illnesses. There is a requirement for better estimates of human exposure to environmental levels of biological, chemical and physical agents as they relate to adverse health effects.

In order to adequately assess the impact of most pollutants on health, an integrated (multimedia) monitoring system is necessary to furnish an accurate estimate of exposure that can be used to determine the exposure–dose–response assessments needed for scientifically defensible environmental health criteria. When measuring the exposure of a receptor to chemical or physical agents, data from the integrated monitoring system should quantitate the contribution of each pathway and the chemical or physical form of the pollutant.

Biological monitoring can be an important part of an air monitoring program. For many pollutants the major pathway from source to receptor is through the air. The monitoring of tissues and biological fluids collected from receptor plants, wildlife, domestic animals and humans can indicate levels, patterns and trends of atmospheric pollutants or their metabolites. For example, the first indication of air pollution damage is generally detected by adverse changes in living tissue. The health, growth and number of plants, or the accumulation of a pollutant within a plant, may be a useful indicator of an environmental pollutant that may adversely affect human health. Another example is that incidences of pollution are often detected by unusual changes or mortality in animal populations caused by pollutants such as DDT, mercury, cadmium, lead, fluorides, and arsenic. Valuable information on lead, selenium, mercury and arsenic exposures may be furnished by the analysis of selected human tissues and fluids such as hair, teeth, fingernails and blood.

Components of a monitoring network

To provide valid data on pollutant concentrations, an air quality monitoring network must have the following essential components: a central laboratory facility; a manual sampling network; an automatic network; and support facilities.

No matter how sophisticated the facilities are in the field, a central laboratory is necessary to supply the following:

- analytical expertise for operating the total network
- quality control services for the total network
- primary standards for all pollutants
- preparation of reagents and filters for the manual sampling network
- laboratory analysis of samples from the manual sampling network
- primary standardization of systems used for field calibration of continuous monitors in the automatic network
- special surveys and analytical support (e.g., for emergency episodes)
- specialized personnel and instrumentation for research projects.

The manual network is the most efficient first step in establishing a total network. This system can provide basic data upon which a comprehensive network can be designed. The manual network provides 24-h integrated measurements of total suspended particulates, SO_2, and NO_2. A most important feature of this network is that valid data can be rapidly obtained with relatively simple and inexpensive field sampling equipment — the high-volume sampler and the manual gas sampler. Both of these samplers provide 24-h integrated samples for measurement of particulate burden and gaseous pollutant concentrations, respectively.

Airborne particulates are collected on the glass-fiber filter of the high-volume sampler, and the filter weight increase is a measure of the total particulate loading. The filter also provides sample aliquots on which analyses may be made for sulfate (acid aerosol) and toxic elements such as lead, cadmium, arsenic, beryllium, and mercury. Such filters may be stored in a sample bank for years for further historical analyses.

The high-volume samplers require some special associated equipment. Before and after sample collection, the glass-fiber filters must be conditioned in a controlled environmental chamber at a specified, controlled temperature and humidity.

In addition, a specially designed microbalance is required for gravimetric analysis of the filters. During sampling, the high-volume sampler flow rate must be controlled at a known value. Flow-rate calibration is performed by using devices such as calibrated orifices or wet-test meters.

The manual bubbler contains a pre-prepared gas absorber reagent for the collection of 24-h samples for SO_2 and NO_2 analysis. After contact with ambient air for a specified time, the aqueous samples are collected in the field and returned to the laboratory for analysis. Adequate wet-chemistry bubbler techniques such as the West-Gaeke and the EPA reference (arsenite modification) techniques are available for the analyses of SO_2 and NO_2, respectively. Twenty-four-hour bubbler techniques are not currently available for ozone, carbon monoxide, and hydrocarbons.

The automatic network will provide continuous in-situ measurements of pollutants. This is really the only feasible way to get peak and diurnal concentrations of pollutants. In the long run, the automatic network is the most accurate and economical means for measuring the usual spectrum of pollutants.

An automatic network does require, however, some major types of support equipment. A fully equipped mobile laboratory is required for calibration of field stations, for quality control functions, for pollutant-profile studies, and for interrelating monitoring systems. Meteorological support equipment is also needed at all stations. An automatic network for multipollutant monitoring represents an extensive investment and demands that site location, station design, instrument selection, instrument calibration, and data acquisition and handling be carefully considered.

Siting automatic stations

Automatic stations should be located at a site at which pollutant concentrations are representative of a given area of population exposure. Pollutant concentrations at the site should not be unduly influenced by local objects, such as nearby stationary emission source, major traffic arteries, high walls or buildings, trees, or highly localized meteorological conditions. Ideally, the site should be located according to an atmospheric model that predicts concentration isopleths and the minimum number of stations required for area monitoring and model verification.

In the absence of all the information required to define an atmospheric model (emission inventories, emission factors, meteorological conditions, transformations, sinks), automatic stations should be located on a movable platform, such as a trailer, to facilitate relocation as required. Because of the sophisticated instrumentation contained in the station, the interior must be controlled within fairly narrow limits for temperature (±2.5 °C) and line voltage (±2 V). In addition, the station interior should have adequate space, including bench-top space, available for calibration systems, gas cylinders, and minor instrument service and repair.

The design of the air-sample inlet and manifold system requires special consideration. In general, the air sampling inlet should be located several meters above the ground to avoid street pollution, eddy currents, and ground-level sinks. The inlet should have a dust cap to prevent heavy particulates, precipitation, and insects from entering the manifold system. Sample air is pulled through the inlet and sample manifold by a high-speed blower or pump (100 L/min). Laminar flow through a wide diameter (50 cm or greater) inlet is desirable to avoid pollutant wall loss upstream of the inlet for the calibration gases. Provision must be made for the dynamic introduction of calibration gases so as to be able to calibrate the complete sampling system from the manifold through individual instrument sampling tubes, filters, and valves, including the detector component of the instrument. Finally, the air-sample inlet manifold should be easy to disassemble for cleaning purposes.

Valid pollutant concentration measurements cannot be made without adequate instrumentation; thus, the selection of instruments for individual pollutants must be given due attention. Instruments should meet certain guaranteed performance specifications for accuracy, sensitivity, zero and span drift, freedom from interferences, response time, and maintenance requirements. Fortunately, considerable information and expertise is available based on previous instrument evaluation programs. (The U.S. EPA equivalency document, 40CFR53, February 1976, is one such source). Such information may be used to provide guidelines on instrument performance to be expected for a given pollutant, and for performance specifications to be included in procurement contracts.

Many commercial sources of air pollution monitors are available. Based on extensive experience, EPA scientists have designated certain operational principles of measurement that have led to the development of instruments with proven performance in the field of monitoring. These are: for sulfur dioxide—coulometry, flame photometry; for ozone—chemiluminescence (gas-phase) or ultraviolet photometry; for carbon monoxide—non-dispersive infrared spectrometry; gas chromatography (conversion to CH_4) with flame ionization; for oxides of nitrogen—chemiluminescence; and for hydrocarbons—gas chromatography with flame ionization.

Handling the data, quality control

The continuous operation of an automatic station generates a copious amount of data. The acquisition, handling, storage, retrieval and utilization of such data require a large investment in data systems and manpower. Automatic-data-acquisition systems are necessary for handling such large amounts of data (*ES&T*, July 1976, p 632). In operation, the analog output of each instrument is sampled at periodic intervals (for example, once a minute). The analog data are converted to digital form and stored on magnetic tape for computer processing. The computer takes the digital data, compares it to calibration input, computes concentration units, makes corrections for zero and span drift, and makes computations such as 5-min, hourly, or 24-h averages.

Two major problems can occur with the automatic data acquisition system. Instrument malfunction may frequently cause anomalous outputs that can lead to serious errors in computer hourly or 24-h averages. Failures may also occur in the transmission of data from the instrument analog to the computer. This is particularly true when data are being "telemetered" from a remote location to a central computer facility over telephone lines. For these reasons, it is most advantageous to have analog strip-chart recorders available for each instrument. These will serve as backup data acquisition systems and provide permanent records that may be used to validate the computer output.

A quality control program ensures that all the necessary steps are taken to assure that monitoring data and supporting information upon which decisions are based are legally and scientifically defensible. A quality control system is necessary if data generated by one network or one laboratory are to be comparable to similar data produced elsewhere or at another time. It is only through such a program that the accuracy and precision of the data are known.

One of the major moves throughout various U.N. agencies involved in environmental monitoring, as well as OECD, SCOPE, and several individual countries, is to establish reference methods. Reference methods are those techniques that have been thoroughly studied and tested and about which we know the limitation, interferences, accuracy and precision. Once a method has been designated as a reference method, it is usually accepted by both the academic and industrial communities as being reliable and specific.

In some cases, the analytical chemist or engineer prefers to use state-of-the-art techniques instead of reference methods. This is acceptable provided the newer technique is statistically comparable to the reference method in the environment in which the measurements are to be made. This is necessary because sampling techniques, instrumentation, quality of chemical reagents and personnel habits vary from one laboratory to another. During interlaboratory comparisons, many systematic dis-

discrepancies have been observed between results of measurements of the same pollutant concentrations in the same media.

It is necessary that all operational phases of a monitoring network system be considered in a quality control program for example sampling, sample handling and storage, sample preparation, sample analysis, instrument performance, data calculations, data validation, data reporting, and data evaluation. In addition, any such quality control program must be applied in field operations for selection of sampling site, verification that the sampling site is directly representative of the area, size of sample collected, sampling rate, and frequency of sampling. All of these parameters must be specified so that resulting data fulfill the goals and objectives of the monitoring network system.

Guidelines and operational manuals for implementing and for operating a routine quality control program must be available for: laboratory construction; selecting qualified personnel; obtaining and testing environmental samples; and obtaining and handling the data correctly.

Future directions

Generally, the speed of airborne remote-sensing devices, which were referred to earlier in the article, is such that three-dimensional plots of the measured parameter are possible before any significant transport of pollutant can take place when appropriate data acquisition and processing equipment are used. A very persuasive case can be made for remote sensing, especially in terms of cost effectiveness. The principal handicap at present is the limited number of parameters capable of being measured remotely and quantitatively. Two parameters that can be measured are: particulate matter, by using airborne LIDAR, a system that is operational; and ozone, with a dual wavelength laser absorption system, which is in the testing phase.

Aggressive R&D programs are under way that address many other pollutants. Factors also under investigation include the feasibility of using ground-based lasers and networks of retroreflectors for multiple pass analysis in a horizontal direction. As these new devices become available, they should be incorporated into operational monitoring systems.

There is no doubt of the ever-increasing importance of remote sensing for EPA's monitoring programs. Yet these techniques will not replace contact monitors; rather they will supplement and improve monitoring methodology. As newer techniques and hardware become available to enhance our ability to monitor our environment we will be faced with the question: "What is the most cost-effective combination of fixed, mobile contact and remote sensors for a specific monitoring problem?"

In the past, environmental monitoring has been done in response to an already existing hazardous condition. Future monitoring systems must be able to detect potential problems and monitor the appropriate parameters before they reach crisis proportion. Some possibilities that might be explored are the use of biological exposure indicators as trend monitors to predict changes, and the development of personal dosimeters, most likely biochemical measurements that integrate the total exposure of an individual to a pollutant or class of pollutants. When we achieve accurate, valid and broadly applied exposure monitoring, we then shall have achieved the ability to truly and rationally manage our air resources.

George B. Morgan *is acting director, Environmental Monitoring and Support Laboratory at Las Vegas, Nev., in EPA's Office of Research and Development. Mr. Morgan is a member of the U.S. delegation to the UN Environmental Program Working Group, and to the US/USSR Joint Working Group on Cooperation in the Field of Air Pollution Modeling, Instrumentation and Measurement Techniques.*

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